EXHIBIT 8

An Introduction to Semiconductor Devices

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McGraw Hill Higher Education

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Exercise Problem

EX3.9 Determine the fraction of total holes still in the acceptor states in silicon at $T = 300$ K for a boron impurity concentration of $N_a = 10^{17}$ cm^{-3}. (Ans. 0.179)

TEST YOUR UNDERSTANDING

TYU3.5 Consider silicon with a phosphorus impurity concentration of $N_d = 5 \times 10^{15}$ cm^{-3}. Plot the percent of ionized impurity atoms versus temperature over the range $100 \le T \le 400$ K.

3.5 | CARRIER CONCENTRATIONS—EFFECTS OF DOPING

Objective: Determine the thermal-equilibrium concentration of electrons and holes in semiconductors as a function of impurity atoms added to the material.

In thermal equilibrium, the semiconductor crystal is electrically neutral. The electrons are distributed among the various energy states, creating negative and positive charges, but the net charge density is zero. This charge-neutrality condition is used to determine the thermal-equilibrium electron and hole concentrations as a function of the impurity doping concentration. We will define a compensated semiconductor and then determine the electron and hole concentrations as a function of the donor and acceptor concentrations.

3.5.1 Compensated Semiconductors

Compensated semiconductor

A *compensated semiconductor* is one that contains both donor and acceptor impurity atoms in the same region. A compensated semiconductor can be formed, for example, by diffusing acceptor impurities into an n-type material, or by diffusing donor impurities into a p-type material. An n-type compensated semiconductor occurs when $N_d > N_a$, and a p-type compensated semiconductor occurs when $N_a > N_d$. If $N_a = N_d$, we have a completely compensated semiconductor that has, as we will show, the characteristics of an intrinsic material. Compensated semiconductors are created quite naturally during device fabrication as we will see later.

3.5.2 Equilibrium Electron and Hole Concentrations

To determine the electron and hole concentrations as a function of the impurity donor and acceptor densities, we use the concept of *charge neutrality.* We equate the density of negative charge to the density of positive charge in the semiconductor. Figure 3.14a is the energy-band diagram showing the negative charges in a semiconductor. These charges include the density of free electrons and the density of ionized acceptors. Figure 3.14b is the energy-band diagram showing the positive charges in